CONSTRUCTION AND OPERATION OF THE McMASTER NUCLEAR REACTOR

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Introduction

The McMaster Nuclear Reactor is a conventional pool-type research reactor. The reactor is currently licensed to operate at a maximum power level of one megawatt. The design power level is five megawatts. However, cooling capacity has been installed for only one megawatt. The reactor is fueled with 18 plate MTR type fuel elements. Each standard fuel element contains approximately 196 grams of U^{235} at 93% by weight enrichment.

The reactor is located on the McMaster University campus in the centre of a residential area in the western end of the City of Hamilton. The high population density around the reactor site, plus the fact that this was the first reactor to be built in Canada outside of a government laboratory, led to the decision to provide for a moderately high degree of containment in the reactor building design. The building is a fifteen-sided reinforced concrete structure, eighty-six feet in diameter. It is designed to have a leakage rate of less than ten percent of the building volume per day at a differential pressure of one-half pound per square inch. This corresponds to a total leakage rate of twenty-five cubic feet per minute.

The building is completely air conditioned. In normal operation the building pressure is maintained one-eighth of an inch of water below atmospheric pressure. All exhaust air from the reactor building is filtered by Cambridge Absolute Filters. The air intake and exhaust ducts are equipped with power-operated valves to seal the building if required. Three personnel air-locks and one equipment air-lock are provided.

The reactor first achieved criticality 4 April 1959 and has been in routine operation since mid-September 1959.

Reactor Project Time Schedule

McMaster University has been actively engaged in nuclear research since 1943 when Dr. H. G. Thode was asked to conduct some studies for the newly-formed Canadian atomic energy project. A close association has been maintained with the national project since this date. By 1955 some ten members of the Science Faculty and about twenty-five graduate students were actively engaged in nuclear studies. These men were making use of reactor facilities at Chalk River, Brookhaven and Los Alamos.

It was decided, in the fall of 1955, that further expansion of research in the nuclear field could not be readily accomplished without a reactor at the University. At the same time expansion of the University into the field of engineering studies was being planned and it was felt that a reactor would be a useful tool for training and research in several fields of Engineering.

A study carried out by the science staff indicated that the proposed reactor should have a maximum degree of flexibility

and an initial neutron flux of approximately 10^{13} $n/cm^2/sec$, with provision for increased flux levels in the future. A survey of available reactor designs led to the decision that the most economical solution to these requirements would be a pool-type reactor operating at an initial power level of one megawatt with provision for future operation up to five megawatts.

In November 1955 a brief was circulated to local industry and to government agencies outlining the proposed project and requesting financial support. Assurances were obtained by June 1956 that adequate funds could be obtained.

Conceptual specifications for the reactor were drawn up and six firms were requested to bid on the detailed design and construction of the reactor proper in August 1956. The bids were received 15 October and, after evaluation by the University Science staff, AMF Atomics (Canada) Limited was awarded the contract in November 1956.

Detailed design of the reactor building was not started prior to awarding the reactor contract. This procedure was followed to ensure proper integration of the reactor system into the building design. Tenders were called for the building construction, including the reactor shielding, in June 1957 and construction commenced at the end of August. Construction work was substantially completed by March 1959. A few minor items were not completed until June 1959, nearly three months after the reactor went critical.

Construction

Two separate contracts were awarded by the University concerning the complete construction of the reactor. AMF Atomics (Canada) Limited was engaged to design, supply and instal the reactor equipment. The building construction, including the reactor pool, was carried out by Pigott Construction Company Limited. The employment of only two prime contractors almost completely eliminated disputes over areas of responsibility. In addition the same electrical and mechanical subcontractor, Canadian Comstock Company Ltd., was engaged by the two prime contractors. This arrangement is particularly desirable because of the many areas of interconnection between the reactor and building electrical and mechanical systems.

Two major problems were encountered in the construction program. The architect underestimated the problems involved in the design of the air-lock doors. The doors originally installed were inadequate and were replaced with a new design. Tests on the reactor pool before the tile lining was applied showed approximately seventy-five leaks. Major leaks were attacked by cutting and patching on the inside and outside of the pool. The entire inside of the pool was then given a two-coat ironite waterproofing treatment before application of the ceramic tile. This procedure reduced the number of leaks but did not completely eliminate them. At the present time minor leakage is occurring at six points.

A major delay in the construction program was caused by an unusually long period of very cold weather in February and March of 1958. This delay, coupled with other minor delays, put the building well behind schedule. No delays due to late arrival of equipment were encountered.

The leak test on the reactor building containment shell was carried out by pressurizing the building to the design pressure of one-half pound per square inch and measuring the air flow required to maintain this pressure. No particular difficulties were experienced in finding and sealing leaks. This was, however, a time-consuming process and seriously interfered with other work in progress in the building.

Pneumatic Rabbit System

One of the experimental facilities provided in the reactor is a pneumatic rabbit system. This system has three sample irradiation positions in the reactor. Samples are delivered, after irradiation, to receiving stations located in the reactor building and in the adjoining research laboratories. Provision must be made for sealing the rabbit lines leaving the reactor building containment shell. The rabbit lines are 1 1/2" O.D. tubing. Emergency sealing of the rabbit system air lines is a simple problem since standard power-operated valves may be used. The sample carrier lines, however, present a problem since the sealing valve must allow free passage of the rabbit container which is 1 1/4" O.D. x 4 1/2" long.

A survey of standard power-operated valves indicated that a suitable valve was not readily available. A simple, lever-

operated, clamp-type, gate valve (Crane #494) was selected to serve as the basic valve for the rabbit carrier lines. The 1 1/2" pipe size valve was employed. The 1 1/2" O.D. rabbit tubing was slipped into 1 1/2" pipe-nipples in each side of the valve and sealed by caulking. The end of the tubing rested on the edge of the valve seat itself, just clear of the gate in the closed position. The valve was modified for operation with a standard pneumatic actuator. This arrangement provided a completely adequate seal and in no way restricted the passage of the rabbit carrier.

The valves in the rabbit lines are operated by the same circuit which seals the building ventilation system in an emergency. To prevent trapping a carrier in the valve, or having it stop somewhere in the line where it could present a radiation hazard, the closing of the rabbit valves is inhibited if a carrier is in transit in the system. This short delay, five seconds maximum, in sealing these lines is permissable since the lines terminate in glove boxes fitted with absolute filters in the research laboratories.

Administrative Organization

The reactor project organization is shown in Figure 1. The general policy for the reactor is set by the President and Vice-President of the University in consultation with the University Board of Governors and an Advisory Committee composed of leading Canadian scientists.

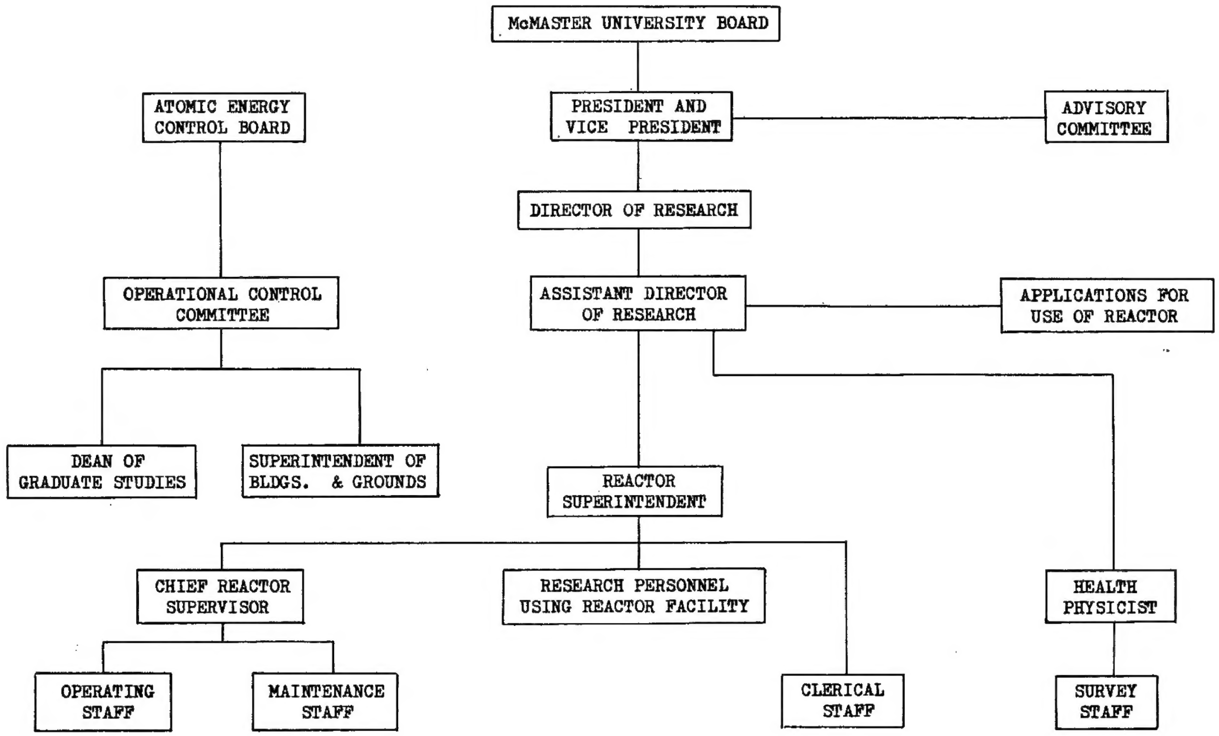

FIGURE 1

McMASTER NUCLEAR REACTOR PROJECT ORGANIZATION

The reactor is operated under conditions imposed by the operating license issued by the Atomic Energy Control Board. Local control of reactor operations and of all use of radioactive material is handled by the Operational Control Committee. This Committee is composed of the Director of Research and his Assistant, the Health Physicist, the Medical Consultant, the Reactor Superintendent and Reactor Supervisor, and representatives of the Departments of Physics and Chemistry. The Committee has the advice of the Dean of the Faculty of Graduate Studies on matters concerning student research programs and of the Superintendent of Buildings and Grounds on reactor building maintenance. The program approved by the Operational Control Committee is carried out under the direction of the Reactor Superintendent.

The full-time reactor staff for the present forty-hour-weekly operating schedule consists of the Reactor Superintendent, Reactor Supervisor, two Reactor Operators and a janitor. In addition, the services of a Health Surveyor are available when necessary. All experimental work is carried out by University staff members and graduate students.

Radiation Hazard Control

Because of the high population density around the reactor site, great care is taken to prevent the release of even small quantities of contamination to the environment. The exhaust air from the reactor and from the radioisotope laboratories

is filtered. The air is monitored after filtration. Four air-sampling stations are in continuous operation around the site. Rainwater, collected on the University campus, is monitored.

Sewage from the reactor building is batch sampled and monitored before discharge to the city sewer. The combined sewage from the reactor building and the research laboratories is continuously sampled before entering the main city sewer. The upper limit for unidentified beta activity in the sewage leaving the University property is 500 micro-microcuries per litre, averaged over one week.

All radioactive waste from the University is shipped to Chalk River for disposal. Shipments are made by private vehicle and are accompanied by a member of the reactor staff.

Reactor Water Purification System

Make-up water to the reactor pool is supplied by a regenerative-type, mixed bed, ion exchange unit with a capacity of 18 U.S. gallons per minute. The low level of activity permissable in water discharged to the city sewer makes the use of regenerative-type ion exchange units impractical in the pool repurification system. This system employs cartridge-type, mixed bed, ion exchange units. Two cartridges, operated in parellel, each containing three cubic feet of mixed bed resin, permit a purification system flow rate of up to 24 U.S. gallons per minute. The exhausted resin is removed from the cartridges

after decay of short-lived activity and shipped to Chalk River for disposal.

The reactor primary system has a capacity of approximately 120,000 U.S. gallons. In practice it has been possible to maintain the conductivity of the primary water at one micromho with the purification system running continuously. Under these conditions the ion exchange cartridges require replacement every four to six weeks.

In practice it has been found essential to keep a close check on the quality of the water leaving the ion exchange units. Nuclear grade, mixed bed, ion exchange resin supplied by two different companies has, on occasion, been improperly prepared. Apparently one of the resins was not completely converted to the hydrogen, or hydroxyl, form. This results in dilute acid or dilute caustic production rather than high quality water. If the pH in the pool is allowed to rise above 8.0 the rate of dissolution of impurities in the water increases to the point where the ion exchange units can no longer compensate for it. If this is allowed to happen it is necessary to first neutralize the water by adding acid. The water must then be transferred from the reactor pool to storage tanks via the demineralizer in such a manner as to treat all the water with a minimum of mixing with water still untreated. Reactor operation must be suspended during this period and the high pH leads to acceleration of corrosion of the fuel element cladding.

Reactor Instrumentation

The instrumentation used in the McMaster reactor is basically identical to that used in most pool reactor installations. The main instruments are standard reactor control units manufactured by Honeywell Controls. In general very little trouble has been encountered in the instrumentation.

One area in which some difficulty has been encountered involves the annunciator and control relays. Contacts on these relays occasionally require adjustment and cleaning. The relays are permanently wired into the circuit and replacement or contact adjustment is a time-consuming task. Experience at McMaster indicates that the added initial cost of plug-in relays would be returned many times over in savings in labor and reactor down time for relay maintenance.

Some difficulty has also been experienced with the safety amplifier. Correction of this problem required changes in the safety amplifier circuit. Later production models of this amplifier have been modified by the manufacturer to eliminate the cause of the trouble. However, since many of these amplifiers are already in use, the following summary of circuit changes made at McMaster may be of interest.

Safety Amplifier Circuit Changes

The standard Honeywell Safety Amplifiers used at McMaster incorporate relay circuits to transfer one rod magnet to a holding resistor if the corresponding magnet control tube filament open circuits. The holding resistor was not installed in the amplifier

because two magnets are connected to one control tube in the McMaster reactor. It was felt undesirable to transfer these two rod magnets from the fast scram circuit to the holding resistor on tube failure. Operating experience showed that the transfer relays occasionally dropped out, presumably due to low line voltage, causing an unnecessary reactor scram. The transfer contacts of the relays were disconnected from the magnet circuits to prevent this. The relay contacts in the annunciator circuit were left unchanged so that annunciation of tube failure still takes place. The transfer feature would appear to be completely unnecessary since no magnet control tube filament failures have been encountered in nine months' operation.

During the first months of operation the shim-safety rods dropped for no apparent reason at random intervals averaging about once a day. The safety amplifier contains two power supplies, one + 300 V and one - 300 V. Each of these supplies is stabilized with two type OA2 gas discharge voltage regulators. Tests with a recording voltmeter showed that the output voltage of each of these supplies suffered momentary sharp drops of at least 20% at infrequent intervals. These drops did not occur at the same time in both supplies and were not caused by line voltage changes. The trouble apparently originates in the OA2 regulator tubes themselves.

The magnet control tube bias is taken from a bleeder chain running from + 300 V to - 300 V. The drops in the + 300 V supply cause interruption of magnet current. The drops in the - 300 V

supply cause increases in magnet current. The + 300 V supply was redesigned and now uses a series regulator circuit in place of the OA2 tubes. It was not practical to modify the - 300 V supply. The increases in magnet current due to the momentary drop in the - 300 V supply occasionally caused one or more magnet fuses to blow. Replacement of these fuses with slow-blow-type fuses has eliminated this difficulty.

Since these changes were completed, unexplained rod release occurs on the average of about once a month compared to once a day previously.

Experimental Program

Several major nuclear research programs have been underway at McMaster for several years. These programs are being expanded and new projects started now that the reactor facilities are available.

The oldest nuclear research program at McMaster is the study of the fission yields in neutron-induced fission. This work has been carried out under the direction of Dr. H. G. Thode and Dr. R. H. Tomlinson. Mass spectrometric and isotope dilution techniques have been used to determine accurate absolute fission yields. This work has produced detailed cumulative yield data for nearly every mass chain from 130 to 154 in thermal neutron fission of U^{233}, U^{235} and Pu^{239}. Less detailed data is available for other mass regions and also for fast neutron fission of U^{238}. This work is now being extended to studies of the short-lived

fission products in an attempt to determine more about the distribution of nuclear change in fission.

Dr. M. W. Johns directs a group studying the mechanism of beta decay. This group employs beta-ray spectrometers, scintillation counting, fast coincidence measurements and angular correlation methods to determine the decay schemes of neutron-rich nuclei. This work, which has been hampered in the past by shipping delays for short-lived sources, is now being expanded. In particular it is hoped that worthwhile investigation of very short-lived nuclei can be carried out using the rabbit system.

A medical research program has been carried on at McMaster for several years. This work has led to improved diagnostic tests for thyroid disorders using I^{131}. Some work has also been undertaken on blood circulation studies using Kr^{85}. This group, directed by Dr. C. H. Jaimet, is undertaking a study of the medical applications of short-lived radioactive isotopes. In particular it should be possible to greatly reduce total radiation exposure in diagnostic tests by making use of short-lived material.

The Department of Metallurgy is using one of the reactor beam ports for neutron diffraction studies of crystal structure. This work, of course, was impossible before the reactor was constructed. The neutron diffraction investigations serve as a valuable compliment to the more conventional x-ray diffraction studies of crystals.

Activation techniques are being used to study multicomponent diffusion in solid metal systems. Radioactive isotopes are being employed as tracers in Chemistry, Biology and Biochemistry. Studies of the Szilard-Chalmers reaction, radiation-induced polymerization and other radiation-induced reactions are being carried out.

An atomic beam apparatus is being used to study the spins, magnetic moments and electric quadrupole moments of radioactive nuclei. Because of the low transmission of the atomic beam apparatus, quite strong sources are used in this equipment. The active material is vaporized in the apparatus and is deposited throughout the system. This leads to considerable difficulty in maintenance and requires that the complete instrument be housed in a room equipped as a hot laboratory.

A total of fifteen separate research programs employing the reactor facilities, or radioactive isotopes produced in the reactor, were in progress by December 1959. Several additional projects are in the planning stages at the present time. Reactor operation is currently restricted to a forty-hour week by budget considerations. A more continuous operating schedule is desirable for several of the research projects and will be undertaken as soon as possible.